

Seasonal Evaluation of Surge Flow Irrigation for Corn

J. T. Musick, J. D. Walker, A. D. Schneider, F. B. Pringle

MEMBER
ASAE

ASSOC. MEMBER
ASAE

MEMBER
ASAE

ABSTRACT

SURGE flow irrigation of graded furrows was successfully managed under field conditions to change a conventional 12-h steady flow set, 400-m (¼-mile) field length, to a 24-h set by using the same field water supply to irrigate a large area per set. The surge flow treatment resulted in reduced total water application during seven irrigations from 1,180 to 814 mm (46.5 to 32.0 in.), reduced water intake from 992 to 733 mm (39.1 to 28.8 in.), reduced tailwater runoff from 189 to 82 mm (7.4 to 3.2 in.), and reduced estimated deep profile wetting below the root zone from 101 to 36 mm (4.6 to 1.4 in.) on moderately permeable Olton clay loam. Surge flow reduced both seasonal water use and grain yields by 6% and did not affect seasonal water use efficiency for grain production. The surge flow effect on reducing water intake of a surface soil loosened by tillage (32%) was almost double the average effect attained (17%) after consolidation of the surface soil by previous irrigation. The results indicate that surge flow irrigation can be managed successfully to reduce excessive water application in graded furrow systems.

INTRODUCTION

Surge flow irrigation is defined as the intermittent application of water in a series of on and off modes of constant or variable time spans (Coolidge et al., 1982). Recent commercial development in electronic surge controllers and valves have led to widespread equipment sales in the Texas High Plains. About 25 units were in operation in 1983, 1,567 units were sold in 1984, and industry representative estimated about 2,000 units were sold the following two years.

In the Texas High Plains, 1.14 million ha (2.82 million acres) were irrigated by the graded furrow method in 1984 (Musick, 1985). Water is pumped from wells in the Ogallala aquifer, distributed to fields through underground pipeline with alfalfa valves on pipe risers, and applied through gated aluminum or plastic pipe. In surge flow systems, water is delivered to the gated pipe through a surge controller valve that alternately delivers the water to equal size field strips on each side of the

controller-valve assembly. In practice, flows of equal rate and time are alternately applied to adjacent field strips. Surge cycle time is the application on time plus the off time.

The intermittent application of water by surge flow affects water infiltration rates (Samani et al., 1985). The surge effect accelerates the normal intake rate decline to the basic rate. Walker (1981) and Coolidge et al. (1982) indicated the infiltration reduction to the basic rate occurs during one wetting and desaturation cycle and no further change occurs in the previously wetted portion during subsequent surges. However, Izuno et al. (1985) indicated the full infiltration reduction effect occurs only for the furrow section that has attained a maximum wetted perimeter.

Most tests with surge irrigation have emphasized the reduction in infiltration. Walker (1981), using flowing furrow infiltrometer tests, indicated typical reductions of 50%. However, in paired level border tests, the reduction in intake during the advance phase was 27%. In subsequent tests, Walker (1982) reported the effects to be greater on sandy soils than on either silt loams or clay loams. Intermittent ponding tests were used by Trout and Kemper (1983) to estimate the intake rate reduction effects as 20 to 30%.

Bishop et al. (1981) emphasized that surge flow effects on water intake were more pronounced on nonwheel track furrows. Surge flow reduced the variability in advance time among furrows, thus more nearly equalizing intake opportunity time among furrows and increasing uniformity of water distribution. Similar results were obtained by Izuno et al. (1985). Bishop et al. (1981) speculated that programming changes in the cycle ratio can be used to achieve cutback flow and effectively eliminate field runoff.

Podmore and Duke (1983) indicated that when the same water amounts were applied in surge flow as in steady flow tests, surge flow reduced infiltration, increased runoff, and reduced application efficiency. However, when surge flow was managed for cutback flow during the runoff phase, tailwater runoff was reduced and application efficiency was increased.

Manges and Hooker (1984) found no infiltration advantage from surge flow during seasonal irrigations of consolidated surface soil that developed shrinkage cracks during soil water depletion. Walker (1984) has indicated that surge flow irrigation of the slowly permeable soils of the Southern High Plains may not be an advantage except when the soil is in a loosened condition by tillage such as during the preplant irrigation. He concluded no efficiency advantage from a preplant irrigation test in which intake was low due to mechanical compaction and surge flow reduced intake from 91 to 68 mm (3.6 to 2.7 in.). However, in a preplant irrigation of the same soil type under much higher intake conditions, surge flow

Article was submitted for publication in October, 1986; reviewed and approved for publication by the Soil and Water Div. of ASAE in May, 1987.

A contribution from USDA-ARS and Soil Conservation Service.

The authors are: J. T. MUSICK and A. D. SCHNEIDER, Agricultural Engineers, USDA-ARS, Conservation and Production Research Lab., Bushland, TX; and J. D. WALKER, Civil Engineer, and F. B. PRINGLE, Soil Scientist, USDA-SCS, Amarillo, TX.

Acknowledgment: The High Plains Underground Water Conservation District No. 1, Lubbock, TX, furnished the neutron meter. P. N. Johnson, Farmer, Friona, TX, managed cultural operations, irrigations, and assisted with data collection.

reduced intake from 386 to 147 mm (15.2 to 5.8 in.). By greatly reducing deep percolation, surge flow increased application efficiency from 34 to 83%.

The literature on surge flow irrigation indicates that benefits may be strongly influenced by management and that minimal work has been reported for whole season tests that included evaluating crop yields. Declining groundwater storage in the Southern High Plains, high pumping energy costs, and low commodity prices have led to major interest in surge flow as a graded furrow irrigation practice to substantially reduce irrigation water requirements by increasing system application efficiencies. The objective of our test was to evaluate surge flow effects under practical field conditions with irrigations managed by an experienced farmer.

Graded furrow irrigations of moderately permeable clay loam soil in the Southern High Plains can result in water intake in excess of profile storage capacity (Musick et al., 1985; Musick and Pringle, 1986). We hypothesize that surge flow can be managed to reduce the excessive intake and to efficiently irrigate a 400-m ($\frac{1}{4}$ -mile) field length as 24-h sets compared with conventional steady flow irrigation as 12-h sets.

PROCEDURE

Surge flow was compared with conventional steady flow application in a graded furrow irrigation study for corn production. The field was uniform Olton clay loam (fine, mixed thermic, Aridic Paleustoll) near Friona in Parmer County, Texas. The soil profile is clay loam with a blocky subsoil structure to the 1.2- to 1.4-m (4- to 5-ft) caliche depth. Below this depth, the clay loam profile contains about 50% calcium carbonate by volume to about 1.8 m (6 ft) and about 25% to the 3.0-m (10-ft) depth. The caliche defines an abrupt boundary for rooting depth by corn. The average available soil water capacity is 16% by volume for a profile available capacity of 224 mm (8.8 in) to 1.4-m (4.5-ft) depth.

Tests were conducted on a 400 m ($\frac{1}{4}$ mile) long field with furrows spaced 1.5 m on 0.25% grade. Corn was planted in 0.75-m (30-in.) rows. Irrigation treatments compared were (a) surge flow application in 24-h using about 45 min on time (1.5 h cycle time) compared with (b) conventional steady flow application as 12-h sets. Furrow flow rates for the steady flow treatment averaged 2.4 L/s (38 gpm). Furrow flow rate for the surge flow treatment was reduced to 1.9 L/s (30 gpm) to limit tailwater runoff. Treatments were evaluated on a 27- \times 400-m (90- \times 1,320-ft) field strip for the steady flow test and on two 30- \times 400-m (100- \times 1,320-ft) adjacent strips for surge flow. The tailwater runoff, soil water, and yield data were collected from one of the two identically managed surge flow field strips.

Water was applied through gated pipe and measured with an in-line propeller meter. Tailwater runoff from all irrigated furrows was measured with a long-throated flume (Replogle and Clemmens, 1981) equipped with a stage recorder. Application starting times and flume recorder charts that showed beginning of runoff were used to determine advance time to end of field.

Irrigations were applied when the profile soil water was depleted to near 50% available in the 1.4-m (4.5-ft) profile. Depletion level taken 1 to 2 days before the six seasonal irrigations averaged 53% available for surge flow and 58% for the steady flow treatment. Seasonal irrigation dates are indicated by data points in Fig. 1.

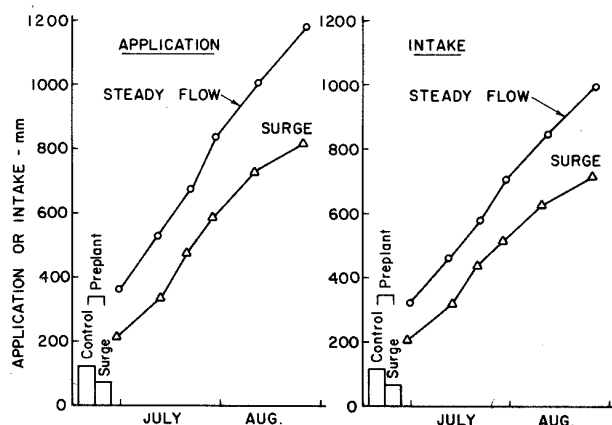


Fig. 1—Cumulative water application and intake for successive irrigations, including preplant application, for surge and steady flow treatments.

Cultural practices for corn production were to shred residues from the previous corn crop, chisel and disk till, and apply fertilizer for high yields. Furrows on a 1.5-m (60-in.) spacing were established and compacted by tractor wheel pass prior to the preplant irrigation. When plants were small, adjacent noncompacted furrows were established during cultivation. The preplant irrigation was applied to the 1.5-m (60-in.) spaced compacted furrows and all seasonal irrigations were applied to the adjacent 1.5-m (60-in.) spaced nonwheel track furrows. Following the preplant irrigation in early April, corn hybrid 'NK PX72' was bed planted on May 1, 1983. Plant densities averaged 5.6 plants per m² (23,000 per acre). Plants emerged in mid-May and reached physiological maturity in mid-September.

The field strip treatments were sampled for soil water contents and grain yields by 100-m (330-ft) length-of-run blocks, with soil water and yield data taken at 30, 150, 250, and 370 m (100, 490, 820, and 1,210 ft) from the head end. Soil water data were taken by the neutron method in two access tubes per length-of-run site. Data from the 8 tube sites per treatment were taken on 17 dates that included before and after preplant irrigation, at plant emergence, an average of 1.5 days before and 2.4 days after the six seasonal irrigations, after completion of grain filling when hand harvested, and after combine harvest. Additional soil water data were taken between some irrigation intervals. Data were taken by 0.2-m (8-in.) increments to 1.2 m (4 ft) and by 0.3-m (12-in.) increments to 3.0 m (10 ft). Soil water contents to the 1.4-m (4.5-ft) depth were used in a water balance to calculate seasonal water use. Soil wetting between the 1.4-m (4.5-ft) root zone and the 3.0-m (10-ft) depth following irrigation was used as a conservative estimate of deep percolation.

Four 5-m² (54-ft²) yield areas were hand harvested in late September at each length-of-run site for a total of 16 field samples per treatment. Ears were oven dried (70°C, 160°F) to constant weight, shelled, weighed, and grain yields were adjusted to 15.5% moisture.

Soil bulk density data were taken on several dates as cores 50 mm (2 in.) diameter by 75 mm (3 in.) deep in the furrow zone after removal of the surface 25 mm (1 in.) of crust or loose soil. Four to eight cores per treatment were taken on each date, oven dried, and weighed for dry density.

RESULTS AND DISCUSSION

Rainfall was above normal (197 mm, 7.8 in.) during the emergence through the early growth period, May through mid-June, and very low (26 mm, 1.0 in.) the balance of the growing season after about 0.5-m (20-in.) plant height. Monthly maximum air temperatures averaged 30 to 35°C (86 to 95°F) for the June to September growing season and averaged 1 to 2 °C (2 to 4°F) above normal. The dry season permitted evaluation of the surge flow application treatment during six seasonal irrigations, one or two more than is normally applied for corn production on this soil.

Water Application

Cumulative water application for the seven irrigations is shown in Fig. 1. When the surface soil was in a loosened condition from tillage, water application during the first seasonal application was 240 mm (9.5 in.) for the steady flow and 141 mm (5.6 in.) for the surge flow treatment. The first seasonal irrigation reconsolidated the loosened surface soil, and seasonal applications averaged 164 mm (6.5 in.) for the steady flow and 128 mm (5.0 in.) for the surge flow treatment. The average for the surge flow treatment excluded the last seasonal irrigation, when application was reduced to 90 mm (3.5 in.) because of a well shut down, and irrigation from tailwater pit storage.

The surge flow treatment was successfully managed to reduce the cumulative steady flow application of 1,180 mm to 814 mm (46.5 to 32.0 in.), a 31% reduction. The reduction was associated with reduced water intake and deep profile wetting and application management that reduced tailwater runoff. Variability in seasonal water intake resulted in some variation in the 12- and 24-h set design application times which averaged 12.3 h for the steady flow treatment and 23.3 h for surge flow.

Water Intake

Cumulative water intake was reduced by surge flow from 992 mm to 733 mm (39.1 to 28.8 in.), an average of 24%, Fig. 1. The effect of surge flow on reducing intake was highest early in the season. The reduction averaged 45% for the preplant irrigation applied to wheel compacted furrows and 32% for the first growing season irrigation in noncompacted furrows. A storm during the preplant irrigation resulted in an early cutoff time and may have affected the response to surge flow application. The 32% intake reduction obtained during the first seasonal irrigation in noncompacted furrows may be a more representative value of surge response for loose surface soil conditions associated with tillage. The average intake declined from 132 mm for steady flow to 110 mm for surge flow (5.2 to 4.3 in.), a 17% reduction during the next four seasonal irrigations. For this comparison, the last irrigation applied to the surge flow treatment from tailwater pit storage was excluded since the reduced water supply necessitated a reduction in furrow flow rates to 1.08 L/s (17 gpm). The reduced application rate probably contributed to the 40% intake reduction by the surge flow treatment for the last irrigation.

The desaturation of a surface soil layer between surges that results in surface soil consolidation and reduced intake during subsequent surges is a pronounced effect when the surface soil is in a loosened condition from

tillage. Later in the season, the reduced intake effect declines when the surface soil layer is consolidated from previous irrigations. Dry bulk densities of noncompacted soil averaged 0.99 Mg/m³ (0.99 g/cc) before the preplant irrigation, 1.13 Mg/m³ at planting, and 1.19 Mg/m³ before the first seasonal irrigation. Before the second seasonal irrigation, surface soil layer bulk density in furrows was 1.29 Mg/m³ and remained at the 1.3 Mg/m³ value for the five subsequent sampling dates through harvest. The increase in bulk density from 1.0 Mg/m³ for a loosened surface layer from prior tillage to 1.3 Mg/m³ for consolidated surface soil after irrigation accounts for a substantial reduction in macro porosity. This porosity reduction may account for the surge flow intake reduction effect of about 32% for nonconsolidated surface compared to about 17% intake reduction after consolidation by irrigation.

The Olton clay loam has a low shrinkage volume with profile water depletion and does not develop the large cracks that dominate the initial infiltration process on Pullman clay loam, the predominant irrigated soil of the area. Shrinkage cracks in swelling clays may moderate the infiltration effect of surge flow (Manges and Hooker, 1984).

Tailwater Runoff

By reducing furrow application rates, surge flow was managed for reduced tailwater runoff. Cumulative tailwater runoff for the seven irrigations is shown in Fig. 2. Runoff totaled 189 mm (7.4 in.) or 16.0% for water applied for the steady flow treatment and 82 mm (3.2 in.) or 10.1% for surge flow.

The approximate 45 min application on time resulted in average surge flow advance time to end of field of 4.5 h, compared with 3.5 h for the steady flow treatment. Normally, water advanced to the end of field in three or four surges and application continued for another 12 cycles.

Reduced tailwater runoff volume may be facilitated by using a short on time during the runoff phase to obtain or approach continuous flow on the lower field section. Alternating surges on the upper and mid field sections come together as advancing fronts that catch up with lower field recession flow and should result in improved water distribution with length of run. Sokora (1984) recommended the on time be reduced by one-half during the runoff phase and a shorter on time may be desirable.

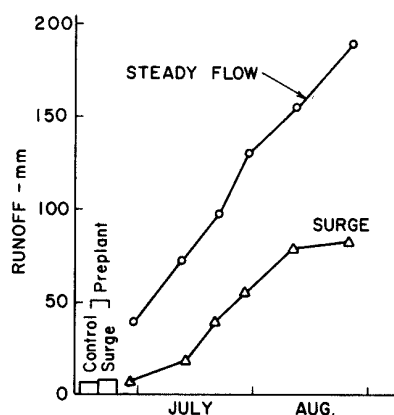


Fig. 2—Cumulative runoff for successive irrigations, including preplant application, for surge and steady flow treatments.

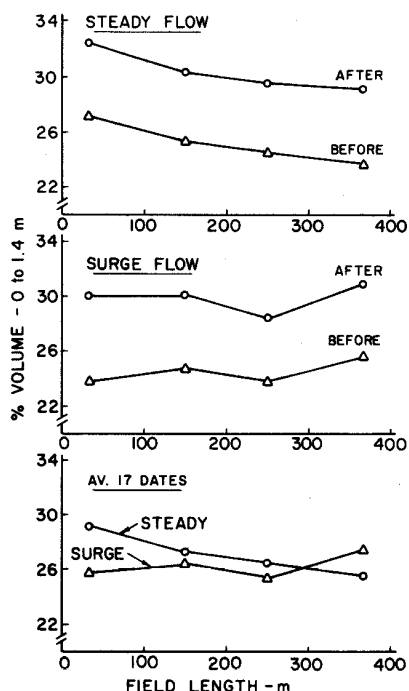


Fig. 3—Average soil water contents before and after six seasonal irrigations and for the 17 sampling dates for surge and steady flow treatments.

Schlegel (1984) further recommended the reduction in on time when the water has advanced three-fourths of the field distance. The surge controller used in the 1983 tests could not be programmed for changing the on time during the advance phase; however, this capability is available on the newer electronic controllers.

Soil Water Contents and Length-of-Run Distribution

Soil water data taken before and after irrigations indicated that the soil profile under surge flow was slightly drier than the steady flow treatment, both before and after irrigation, Fig. 3. However, profile storage by irrigation was similar for the two treatments. Therefore, the 24% reduction in average intake had essentially no effect on profile storage when averaged for the four length-of-run sites.

The season average soil water contents in Fig. 3 indicated that surge flow reduced variability with length-of-run. Surge flow resulted in relatively uniform soil water contents, while steady flow resulted in continuously decreasing water contents down the field. For the surge flow treatment, tailwater was temporarily ponded on a lower field section and channeled into the tailwater ditch at one place for flume measurement. The temporary tailwater backup on the surge flow treatment increased soil water contents at the 370-m (1,210-ft) site, compared with the steady flow treatment which had free furrow outflow into the tailwater ditch (Fig. 3).

Deep Profile Wetting, Seasonal Water Use, and Grain Yields

Wetting below the 1.4-m (4.5-ft) rooting depth, measured from soil water contents before and 2 to 3 days after irrigation, was directly related to intake quantity and antecedent soil profile water contents. Deep wetting was significant for the higher intake irrigations of the

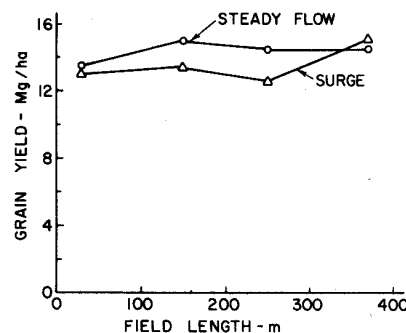


Fig. 4—Grain yields with length of run for surge and steady flow treatments.

steady flow treatment. Surge flow, by substantially reducing excessive intake, reduced cumulative deep profile wetting for the seven irrigations from 101 to 36 mm (4.6 to 1.4 in.). The measured 65-mm (2.6-in.) seasonal reduction in deep profile wetting is a conservative estimate of the reduction in deep percolation losses. Surge flow reduced the calculated seasonal water use from 881 to 823 mm (34.7 to 32.4 in.).

Grain yields at the 30-, 150-, 250-, and 370-m (100-, 490-, 820-, and 1,210-ft) length-of-run sites are presented in Fig. 4. Steady flow yields averaged 14.4 Mg/ha (12,840 lb/acre) compared with 13.5 Mg/ha (12,060 lb/acre) for surge flow, an average yield reduction of 6.5% with the reduction by the surge flow treatment occurring at the 150 and 250 m length-of-run sites. Visual observations indicated no significant plant water stress occurred after beginning the irrigation season until late grain filling when the surge flow treatment showed some visual stress as accelerated leaf senescence. The reduction by the surge flow treatment likely resulted from applying tailwater pit storage during the last surge irrigation and the associated reduction in intake from 145 to 87 mm (5.7 to 3.4 in.). The 58 mm (2.3 in.) reduction in seasonal water use was the same value as the intake reduction during the last seasonal irrigation. Seasonal water use efficiencies for grain production were essentially identical for the two treatments, 1.64 kg/m³ (372 lb/acre-in.) for surge flow and 1.63 kg/m³ for the steady flow treatment. The advantage of the surge flow was more efficient application and associated reduction in irrigation water applied rather than more efficient use by the crop.

CONCLUDING DISCUSSION

A soils inventory of irrigated land in the Texas High Plains indicated that 459,000 ha, or 40%, of the graded furrow irrigated area in 1984 had moderately permeable soils (Musick et al., in process). Since water is pumped from wells and distributed to fields by underground pipeline, the major application losses are deep percolation and tailwater runoff. Since tailwater runoff is commonly reused, the major loss that lowers application efficiency on the moderately permeable soils is deep percolation.

Water intake rates are substantially increased when the surface soil is in a loosened condition by primary tillage. A loosened surface soil is a common occurrence prior to preplant and the first seasonal irrigation. The effect of surge flow application on reducing excessive water is greatest when the soil surface is in a loosened

condition and is likely to be of the most benefit during the preplant and first seasonal irrigation. Other graded furrow tests involving tractor wheel compaction of furrows on the field site used for this study (Musick et al., 1985; Musick and Pringle, 1986) indicted that water intake during seasonal irrigations of nonwheel track furrows normally is 20 to 30% in excess of profile storage capacity. Results indicated the successful use of both tractor wheel compaction and surge flow application for reducing excessive application and intake.

On the slowly permeable soils (2.5-mm or 0.1-in. intake family), high water intake is normally not a problem except during the first irrigation following primary tillage. Surge flow is likely to be most beneficial on these soils during preplant irrigation. During seasonal irrigations, water intake during graded furrow irrigations normally does not fully rewet the soil profile and the use of surge flow to reduce intake may not be a beneficial practice.

The slowly permeable graded furrow irrigated soils in the Texas High Plains are commonly irrigated in 800-m ($\frac{1}{2}$ -mile) runs as 24-h sets, while moderately permeable (mostly 7.5-mm or 0.3-in. intake family) soils are commonly irrigated as 400-m ($\frac{1}{4}$ -mile) runs as 12-h sets. Conventional steady flow irrigation of the moderately permeable soils as 24-h sets is more convenient to the irrigator, but the longer set time increases excessive intake and deep percolation losses. The study demonstrated that the set time on a moderately permeable soil can be increased from 12 to 24 h by using surge flow application that results in 12-h on time without causing excessive intake and losses to deep percolation. A convenient practice is to use surge flow equipment to apply available water supply to twice the area (two normal sets) with the set time increased from 12 to 24 h. The surge flow effect on reducing intake will increase tailwater runoff. However, since tailwater runoff is commonly reused, the increased runoff is a favorable application efficiency trade-off to conventional steady flow application with increased deep percolation losses.

Results from this study and reports of farmer experience in the Texas High Plains indicate that surge flow application to graded furrows on the moderately permeable soils is a successful practice for reducing water application but requires a higher level of management skills to realize the potential benefits. Farmers should be aware that reducing water application

potentially involves the risk of reducing yields and the attainment of the desired yields when using surge flow may require a more frequent application schedule.

References

1. Bishop, A. A., W. R. Walker, N. L. Allen, and G. J. Poole. 1981. Furrow advance rates under surge flow systems. *J. Irrig. Drain. Div.*, ASCE 107(IR3):257-264.
2. Coolidge, P. S., W. R. Walker, and A. A. Bishop. 1982. Advance and runoff-surge flow furrow irrigation. *J. Irrig. Drain. Div.*, ASCE 108(IR1):35-42.
3. Izuno, F. T., T. H. Podmore, and H. R. Duke. 1985. Infiltration under surge irrigation. *TRANSACTIONS of the ASAE* 28(2):517-521.
4. Manges, H. L., and M. L. Hooker. 1984. Field comparison of continuous, surge, and cutback irrigation. ASAE Paper No. 84-2093, ASAE, St. Joseph, MI 49085.
5. Musick, J. T. 1985. Irrigation practices that reduce water application—Southern Ogallala. ASAE Paper No. 85-2599, ASAE, St. Joseph, MI 49085.
6. Musick, J. T., F. B. Pringle, and P. N. Johnson. 1985. Furrow compaction for controlling excessive irrigation water intake. *TRANSACTIONS of the ASAE* 28(2):502-506.
7. Musick, J. T., and F. B. Pringle. 1986. Tractor wheel compaction of wide-spaced irrigated furrows for reducing water application. *Applied Engineering in Agriculture* 2(2):123-128.
8. Musick, J. T., F. B. Pringle, and J. D. Walker. Sprinkler and furrow irrigation trends—Texas High Plains. *Applied Engineering in Agriculture* (in process).
9. Podmore, T. H., and H. R. Duke. 1983. Implementation of surge irrigation. ASAE Paper No. 83-2018, ASAE, St. Joseph, MI 49085.
10. Replogle, J. A., and A. J. Clemmens. 1981. Measuring flumes of simplified construction. *TRANSACTIONS of the ASAE* 24(2):362-366, 374.
11. Samani, Z. A., W. R. Walker, and L. S. Willardson. 1985. Infiltration under surge flow irrigation. *TRANSACTIONS of the ASAE* 28(5):1539-1542.
12. Schlegal, R. 1984. "How to" guide to operating surge irrigation systems. The Cross Section 30(4):3. High Plains Underground Water Conserv. Dist. No. 1, Lubbock, TX 79045.
13. Sokora, G. 1984. Management required for surge use. The Cross Section 30(5):3. High Plains Underground Water Dist. No. 1, Lubbock, TX 79045.
14. Trout, T. J., and W. D. Kemper. 1983. Factors which affect furrow intake rates. *Proc. Nat. Conf. on Advances in Infiltration*. ASAE Special Publ. 11-83:302-312. ASAE, St. Joseph, MI 49085.
15. Walker, J. D. 1984. Field testing of surge irrigation systems. *Proc. Surge Irrigation Conf.*, Texas A&M Univ. Agric. Ext. Serv., Midland, TX, Jan. 11, 1984.
16. Walker, W. R. 1981. Effect of surge flow in level basins. ASAE Paper No. 81-2555, ASAE, St. Joseph, MI 49085.
17. Walker, W. R. 1982. Reduction in infiltration rates due on intermittent wetting. ASAE Paper No. 82-2029, ASAE, St. Joseph, MI 49085.